Effect of Frequency and Duration on Threshold

A Senior Honors Thesis

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ABSTRACT

Noise Induced Hearing Loss (NIHL) is caused by repeated exposure to intense sounds or a short-term exposure to an extremely intense sound, and cannot be reversed or treated. The purpose of this experiment was to develop a test to reliably detect an early onset of NIHL. This specific research covered only the baseline, or the normal hearing results that are going to be used in future experiments involving subjects with mild and moderate NIHL. Past research has shown that individuals with NIHL have a much flatter temporal integration curve (the decrease of threshold with the increase of sound duration) than their normal hearing counterparts. If the most affected frequency is not known, the test can be modified to use brief tones that change in frequency and duration. This is called spectrotemporal integration. Normal hearing subjects do well with longer duration sounds that change in frequency over time, while subjects with NIHL do much better with short bursts perhaps because their brain will interpret each burst as a new sound. Five normal hearing young adult listeners were asked to sit in a sound booth and press “yes” or “no” button when they decided whether they heard a sound or not. Three experimental conditions were used: Temporal Integration (the same frequency at different durations), and two Spectrotemporal Integration conditions: Step (the frequency jumps rapidly in a stair-like pattern with duration), and Linear (the frequency changes gradually with time). The results showed that there is a definite threshold improvement with duration, but it is not clear whether one task is better at improving threshold than and the other two tasks.

INTRODUCTION

Noise Induced Hearing Loss (NIHL) is caused by repeated exposure to intense sounds or a short-term exposure to an extremely intense sound, and cannot be reversed or treated, however it can be prevented. NIHL is a growing concern for reasons like extensive MP3 player use and noisy work environments. It is important to detect NIHL as early as possible because preventative measures can be taken such as minimizing the exposure and using ear protection. Certain pharmaceuticals have been found to protect from sensorineural damage (Kopke et al., 2005). The purpose of this experiment is to develop a test to reliably detect an early onset of NIHL. This specific research will cover only the baseline, or the normal hearing results to be used in future experiments involving subjects with mild and moderate NIHL.

Brief Tone Audiometry is a method that uses tones of different durations to reveal differences between listeners with normal hearing and those with NIHL by testing at the frequency most affected by the noise. Listeners with normal hearing have lower thresholds as the duration of the brief tone is increased from 10 ms to 100 or 200 ms. This improvement is often called temporal integration. Past research has found that subjects with sensorineural hearing loss (which includes NIHL) had a much flatter temporal integration curve than those who have a conductive hearing loss or normal hearing. Seven to 10 dB increase in intensity is required to identify sounds reduced in duration by a factor of 10 such as 100 ms to 10 msec. However it was also established that besides the slight difference in temporal integration slopes between individuals with sensorineural hearing loss and normal hearing individuals, it seems that the rest of the data for both normal hearing and hearing impaired is very similar (Olsen, 1987).

If the most affected frequency is not known, the test can be modified to use brief tones changed in frequency and duration and this is called spectrotemporal integration. It is known that the NIHL is high frequency and is usually between 2,000 and 4,000 Hz, but every person's ears are different (Henderson & Hamernick, 1995). The affected frequencies may vary due to the individual ear physiology (length of the ear canal and hardiness), as well as individual amount of exposure to hazardous noise. In an experiment by Hoglund and Feth (2009) both brief tones and multiple tone bursts of brief tones were used to gather data. The bursts were made up of N 10-ms burst where $1 \leq N \leq 8$. The tones of the same frequency and tones of different frequencies showed the same improvement with the same N. It was clear that the single variable that caused the improved thresholds was the number of tones. No matter the temporal or spectral spacing, or whether spectral or temporal were used alone or together, the threshold improved with increased number of tones (Hoglund & Feth, 2009).

In an ongoing study by Hoglund and Feth, listeners with NIHL also improved when a series of bursts was presented. The hypothesis was that normal hearing listeners' threshold would improve as the duration of signals increased. They would do especially well in detecting the sounds that are a longer duration and change frequency at the same time. There are more chances for an individual to detect a tone if the duration increased and frequencies changed rapidly.

The present experiment was somewhat similar as that of Hoglund and Feth, but with some variation. The main difference is that this experiment used one burst of different duration. Hoglund and Feth used multiple bursts to increase signal durations.

There are two different tones that are used. Unlike in the Hoglund and Feth experiment, multiple short bursts will not be used, only one long burst per duration.

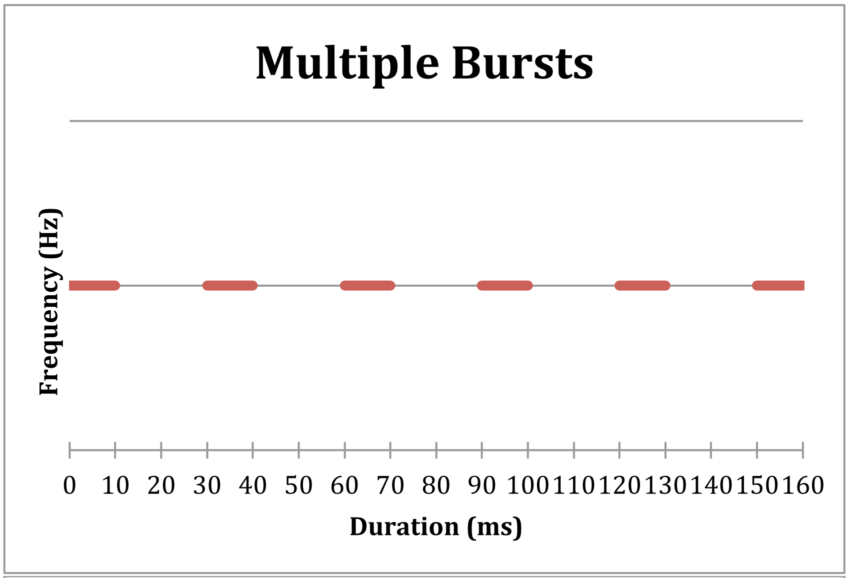

Figure 1. Multiple Bursts used in Hoglund & Feth experiments

10 ms of tone is followed by 10 ms of silence

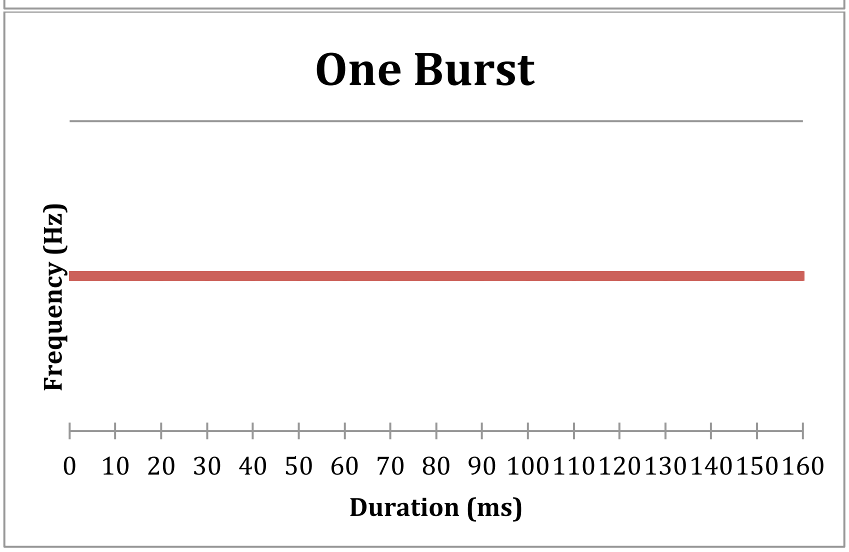

Figure 2. Tones used in this experiment

One long burst is used per duration

LITERATURE REVIEW

Noise Induced Hearing Loss

There may be two causes of NIHL are repeated exposure to fairly intense sounds and brief exposure to extremely intense sounds. Extremely intense sounds of 125 dB SPL or louder such as gunshots pose the most danger to the hearing system since the damage is practically instant and may be quite severe. Less intense sounds of 85 dB SPL or louder may also cause NIHL with repeated or prolonged exposure, so playing loud music or being surrounded by loud environmental sounds may cause hearing loss as well (Henderson & Hamernick, 1995).

To understand why NIHL happens, one must take a look at all parts of the ear that contribute to the way it transmits and processes sound. The outer ear is the part that we can see: the pinna and the external auditory meatus (EAM). This is where the sound is acoustic. The tympanic membrane (eardrum) is the border between outer and middle ear. The middle ear contains three ossicles and the muscles that come with them. The three ossicles are: malleus, incus, and stapes. The two muscles are stapedius and tensor tympani. All these structures form the ossicular chain. This is where the sound is mechanic. The stapes footplate is the last part of the middle ear and attaches to the oval window where the sound transfers into the inner ear. The inner ear contains the semicircular canals and the cochlea. The semicircular canals control the balance system while the cochlea is where sound transfers from hydraulic to neural energy (Henderson & Hamernick, 1995).

The EAM of the outer ear is a tube that is closed at one end by the tympanic membrane. The acoustic resonance properties of the EAM can be described in the equation of a tube closed at one end or:

(f) = speed of sound/ 4 X length of EAM

The length of EAM is approximately 25 mm long, so this makes the average resonance at about 3,200 Hz. This means that the outer ear may amplify sounds up to 20 dB SPL around the frequency midrange depending on the direction and the frequency of the sound. The resonance characteristics of the outer ear affect the acoustic energy delivered to the cochlea (Henderson & Hamernick, 1995). Industrial noise has a very large frequency spectrum, but the outer ear has a band pass noise around 3,200 Hz since this is where the resonance is the greatest. This causes two different things to happen in patients with NIHL. First, it is typical to see a “4 kHz notch” in audiograms of patients with NIHL which is about half octave above the middle frequency of the noise (Henderson & Hamernick, 1995). Henderson & Hamernick (1995) cited studies that have found that the basilar membrane vibrations (a structure in the cochlea) show maximum displacement at half an octave over the stimulation frequency. Another study found that the frequencies where NIHL occurs depends on the anatomy of the patient’s outer ear (Henderson & Hamernick 1995). Since not everyone’s outer ear is 25 mm long, the NIHL may vary in which frequencies are affected. So patients whose ears resonate better at 2 kHz, will get a bigger threshold shift at that frequency, as opposed to patients whose ears resonate better at 4 kHz. The patients whose EAM resonates at 4 kHz will have a greater hearing loss around that frequency (Henderson & Hamernick, 1995.) This shows that NIHL may affect a wide range of frequencies, so testing for NIHL at only specific frequencies such as 4 kHz, may not detect every person with NIHL.

The middle ear's main function is to match the impedance of outer and inner ear. There is about a 40 dB loss between the outer and inner ear due to the transmission of acoustical energy into fluid, so the middle ear is the mechanical energy that fixes this problem. The tympanic membrane attaches to the malleus. The malleus is in a chain followed by incus, and the stapes. Every bone in the chain goes from the biggest malleus to the smallest stapes. Since the energy is the same but the area gets smaller each time, the intensity of the energy increases. This system is a low pass filter with a cutoff at 1,200 Hz, so it tends to attenuate high frequencies above 4 kHz. This is also why the sound detection at higher frequencies tends to be much worse than at lower frequencies. The middle ear also offers some protection against loud sounds. The acoustic reflex is when the muscle of the middle ear flexes, stiffening the tympanic membrane, and pull the stapes perpendicular to the oval window. Although this reflex is very useful at protecting the ear from very loud sounds, it only works below 2 kHz, and is not fast enough for something like a gun shot (Henderson & Hamernick, 1995). This also shows why NIHL is usually at or above 2 kHz.

The inner ear contains a shell shaped structure called the cochlea. The cochlea transmits sound to the auditory nerve, which then transfers the sound information to our brain. The cochlea is a fairly complex organ. This organ contains structures called hair cells. There are two types of hair cells: inner hair cells or (IHCs), and outer hair cells, (OHCs) that sit on the basilar membrane. Each of the hair cells contains rows of stereocilia that look like rows of tiny hairs. When the stapes footplate pushes against the oval window, it causes a fluid displacement in the cochlea, which then causes basilar membrane movement. When the basilar membrane moves due to fluid displacement, a displacement happens in certain parts depending on the frequency of the sound. The stiffness and mass of basilar membrane change greatly from base to apex. The basilar membrane is usually thinner and more stiff at the base and more floppy and thick at the apex. So the wave envelope of sound causes more displacement at the base for high frequency sounds and more displacement at the apex for lower sounds. This causes the shearing motion between the hair cell stereocilia and the tectorial membrane that is right above the basilar membrane. Shearing may cause two different events depending on the direction of the shearing. An excitatory response happens when the bending of stereocilia happens towards the spiral ligament. Bending towards the opposite side has the opposite reaction (Yost, 2005).

When the ear is exposed to loud sounds, the hair cells start beating against the tectorial membrane and may get damaged. This is how NIHL is caused. It is bad enough that hair cells are affected by loud noise, it is evident that other cells and parts of the basilar membrane are affected as well. Besides the death of hair cells, herniation (blood loss), scaring, and major other problems can affect the membrane overall. Anything that is affected by the fluid displacement in the cochlea may also be affected such as the Organ of Corti. All of these factors contribute to the severity of NIHL. The hearing loss can affect anything from the hair cells themselves to, in severe cases, the vasculature of the cochlea. Sometimes the actual auditory nerve is affected as well

(Henderson & Hamernick, 1995). This is why it is so important to detect early onset of NIHL and take action before the damage can really take effect.

Brief Tone Audiometry

Brief Tone Audiometry refers to the use of very short tones to detect a difference between normal hearing and subjects with hearing loss. Olsen (1987) wrote an important review of several studies that were done in the field of brief tone audiometry. The review covered experiments made for normal hearing subjects and those with sensorineural hearing loss. It was found that normal hearing subjects' thresholds increased with increased duration of brief tones. However, subjects with sensorineural hearing loss had a much flatter temporal integration curve than those who have a conductive hearing loss or normal hearing, and that 7 to 10 dB increase in intensity is required to identify sounds reduced in duration by a factor of 10 such as 100 ms to 10

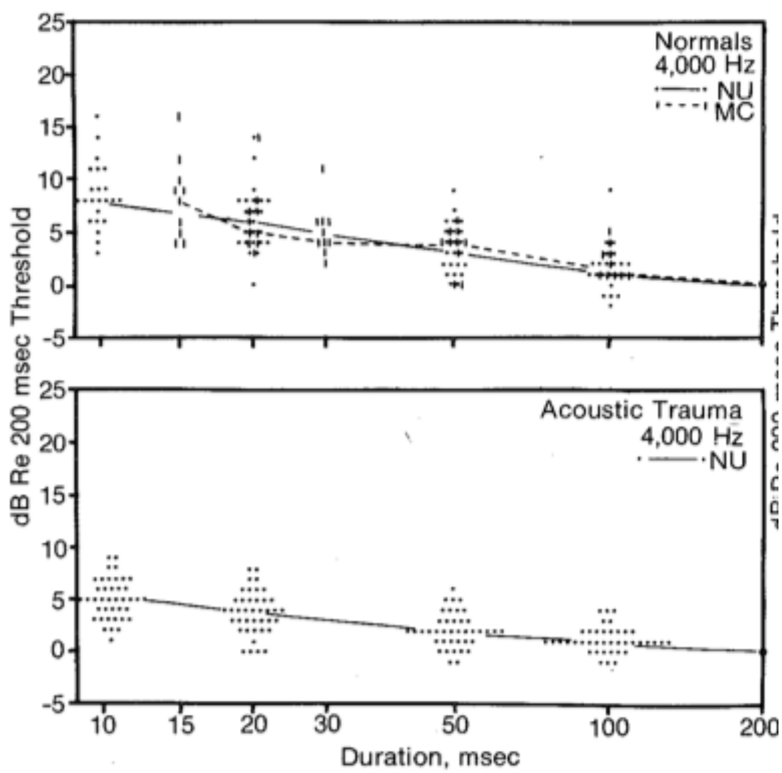

Figure 3: Thresholds of Normal and Acoustic Trauma (NIHL) using brief tones at 4,000 Hz. (Taken from Olsen et al., 1974).

- *X axis = duration of brief tone*
- *Y axis = dB improvement*
- *0 dB is the original threshold at 200 ms*
- *Negative dB denotes threshold improvement, positive denotes decline in tone detection*
- *The dots denote individual subject variability*

Normal hearing subjects have a threshold improvement of approximate 8 dB from 10 to 200 ms Acoustic Trauma subjects have a threshold improvement of approximately 5 dB from 10 to 200 ms (Figure 3).

Olsen also stated that Miskolczy-Fodor (1960) observed in his research a greater degree of recruitment (abnormal loudness sensitivity in hearing-impaired individuals) for severe sensorineural hearing losses, and that Elliott (1963) reported a less steep temporal integration slope (threshold improvement over duration of sound) as a function of the severity of the hearing loss. These findings led to a greater interest in using brief tone audiometry to predict sensorineural hearing loss. Elliott's findings were confirmed when two other studies found an inverse relationship between the degree of hearing loss and the slope of temporal integration. A study done in both quiet and in noise had also found that subjects with sensorineural hearing loss have a less steep slope at frequencies that were affected by their hearing loss with the same pattern in quiet and in noise.

Olsen (1984) indicated that brief-tone audiometry might be unusually sensitive to cochlear involvement. This is because less steep slopes were observed in subjects with sensorineural hearing loss even though their hearing sensitivity was normal at the test frequencies. Olsen's study also shows Jerger's (1955) results which are interesting in this regard. He exposed his subjects to intense noise for 2 minutes, then recorded their threshold shift, and found that the threshold shift was larger for longer tones. This means that this threshold shift caused the temporal integration curve to be flatter than the curve prior to the noise exposure. In other words, he simulated the curve found in subjects with cochlear pathologies which may include NIHL. The mechanism behind this less steep integration phenomenon is not known but it was hypothesized by Wright (1977) (Olsen, 1987) that extremely rapid adaption at the cochlear level is not letting the full energy of a longer sound to be utilized thus causing a much smaller threshold improvement at longer tones. This smaller threshold improvement causes the flatness of the slope of a sensorineural hearing loss subject. However, this would also cause the acoustic reflex (involuntary muscle contraction of the middle ear) thresholds to be different. Research shows that there is not difference in acoustic reflex thresholds in people with sensorineural hearing loss, so the cause of the less steep slope is still not known. It is also important to know that brief tone audiometry does not distinguish very well between different sensorineural hearing losses, so that subjects with VIII nerve lesions and subjects with cochlear pathologies such as NIHL will get very similar threshold curves. It was found that subjects with VIII nerve lesions or tumors do have extremely steep slopes between 1000 and 4000 Hz with durations of 10 to 200 ms (Olsen, 1984).

Spectral and Temporal Integration of Brief Tones

A 2009 study by Hoglund and Feth researched temporal and spectral brief tones. This study came about due to the interest in temporal processing of sound and processing within the frequency domain. The study asks, "How do we achieve both fine acuity (resolution), of the 'small picture,' and also wide integration (summation) of the 'big picture'?" Having superior frequency selectivity needs narrow auditory filters, and fine temporal acuity demands really brief time windows. Yet integration over long signal duration, or a large frequency range shows that the processing window needs to be prolonged. This experiment is different in the fact that, unlike past experiments, this one does not hold either temporal or spectral conditions constant while varying only one of them at a time. They used equivalent and different spectral and temporal step sizes, and randomized frequency presentation. Then the data were analyzed with regards to the spectral and temporal step size, frequency range, slope and the direction of frequency change, and predictability.

Hoglund & Feth (2009) also stated that some past work on the same subject of temporal and spectral summation used the energy detector model. The idea is that the auditory system sums up the signal energy across N tones. Each tone was set to be equally detectable with the use of $d_i' = (2E / N_0)^{1/2}$ (E = energy, N_0 = spectrum level of the background noise). The detectability should also improve with the addition of tones accord to the model. The claim is that the threshold should improve by about 3 dB for each doubling of number of tones (or duration of the sound). Unfortunately, most subjects do not reach this kind of improvement in spectral or temporal summation tasks. A more common improvement is found with $-k \log(N)$ with $k < 10$ (Hoglund & Feth 2009).

The temporal processing theory that was used in this study was the “multiple looks” model which suggests that the auditory system uses “looks” or short time continuous windows at the acoustic input. This means that one look can detect a brief sound, and as the duration of the sound increases, the more looks are used. The information from these looks collects for detection, which then explains the improved threshold at longer duration signals. Viemeister and Wakefield (1991), the authors of the multiple looks model, conducted an experiment with 200 μs pulse pairs separated by 1 ms. The subjects exhibited 4 dB improvement for the pulse pairs compared to single pulse. They also noticed that the threshold kept increasing until the separation reached 5 ms. No changes were found after 5 ms. This indicated partial intergration up to 5 ms, and integration in a single window at 1 ms. After this, they inserted noise in the middle 50 ms of a 100 ms separation. The threshold of two pulses then decreased by about 2.5 dB compared to one pulse independent of the level of noise. This consistent improvement of threshold disproves the energy detector model, and shows that individuals use intelligent processing of sounds in the multiple looks model.

Hoglund & Feth (2009) also stated that research by Buus (1999) showed that the detection of pulses is more or less independent of the other pulses in the same sequence, and does not depend on the masker. He also found that the improvement in detection depends on the type of masker used; pulses masked by a single-band and maskers with unrelated energy envelopes have a slower detection growth than maskers with several bands of identical energy envelopes. Kidd and his colleagues, after working with multiple looks in informational maskers, argued that regularity in the signal allowed streaming to enable detection (Hoglund & Feth, 2009).

In spectral processing, the critical band is important. It is the limit or look for spectral integration. Critical band is the bandwidth frequency of the auditory filter. Auditory filters boost one frequency and attenuate another (Yost, 2005). However, Spiegel (1979) found that the signals beyond the critical band may become bands of their own thus adding energy to the system. The threshold decreased at the rate of 10 log (N). These results were consistent with the energy detector model. He used a masker noise with bandwith of 100- 3000 Hz, and realized that spectral integration may happen through the entire span of audibility (Hoglund & Feth, 2009). Another researcher, Green(1958), established that when frequency was not certain in single tones, the detectability decreased by 3 dB at most in very extreme cases of frequencies varying between 500 Hz and 4000 Hz. This shows that not being able to predict the tone frequency, affected the detectability very nominally (Hoglund & Feth, 2009). Van den Brink and Houtgast (1990) who studied longer tones of 100 ms, also found that multiple brief tone signals had a greater threshold improvement than longer signals of the same total duration. Brief tones were integrated at 8 log (N) while long tones were integrated at the rate of 5 log (N). These results were the opposite of the energy detector model that stated that long tones should have an integration of 10 log (N). This also worked for temporal integration when the signal bandwidth was smaller than one critical band (Hoglund and Feth, 2009). Hicks and Buus (2000) tested psychometric functions of brief tones versus longer tones and found that brief tones had an integration function of 8 log (N) while long tones had 5 log (N) which also disproves the energy detector model (Hoglund & Feth, 2009).

Spectrotemporal conditions are those that change in frequency and duration. There have not been many experiments done in this field, so it is difficult to tell if the multiple looks model is consistent when there is a change in both duration and frequency at the same time. Hoglund and Feth also wrote that Spiegel (1979) has stated that the auditory system is very flexible, and his data supported the notion that spectral and temporal processing are both flexible. In 1997, Grose and Hall stated that the differences in temporal integration of signals may have been, in part, the cause of the disparity between their decrement detection and gap detection experiments(Hoglund & Feth, 2009). Dai and Green (1993) found that frequency spacing of brief tones is what matters in threshold improvement rather than how many tones are used. The farther away the frequencies that were used, the bigger the threshold improvement (Hoglund & Feth, 2009).

The Hoglund and Feth experiment was based on all these studies. The experiment included tones of different frequencies, different durations, and different gap durations. They found that the one variable that resulted in improved thresholds was the number of tones. The spectral integration task yielded 1 to 2.5 dB improvement for each doubling of number of tones and fit the 5 log (N) function, not 10 log (N). The temporal task yielded 1.98 to 2.47 dB for each doubling and fit the 8 log (N) function the best. In spectrotemporal tasks, they found only a 1.74 dB improvement from one to four steps. The linear regression line was a bad fit to any of the threshold improvement models with the best being at 5 log (N). Their task of random frequencies closely matched their results for thresholds of signals with equivalent spaces and best fit the model of 5 log (N). The studies conducted in this experiment were indeed consistent with the multiple looks model instead of the energy detector model (Hoglund & Feth, 2009).

Two questions were asked in this thesis. Can this study replicate the original brief tone experiment? If it can, will there be a difference in the data of the original brief tone task and the two new spectrotemporal tasks? The Temporal was modeled after the brief tone experiment done in the past such as the one done by Olsen (1974) (Figure 3), while the Linear and Step tasks represent the new spectrotemporal condition. We compared our Temporal results with the past results to see if we succeeded in replication. If the Temporal condition did replicate brief tone then it is safe to compare the Temporal task to the two spectrotemporal tasks to see if frequency change makes a difference in hearing threshold. If the replication was not successful then it would not have been clear whether an error occurred in the experiment.

METHODS

Subjects

The subjects were 5 young adults (ages 19 – 39 years) with normal hearing who had participated in previous experiments in the Psychoacoustics Lab at Ohio State University. The subjects were all female students from The Ohio State University. These subjects had air conduction thresholds of ≤ 20 dB hearing level (HL) at the frequencies between 250 - 8000 Hz, and normal otoscopic results. Listening experience was not required for the experiment as long as some introductory training is completed so that the subjects established familiarity with the signals and procedures.

Procedures

First, the individuals did a baseline test that recorded their threshold. Then, the individuals listened for two different conditions. The listeners were asked to go into a sound booth containing a computer, and start the experiment. All of the listening was done on the right ear with supra-aural headphones. Their task was to press the “yes” or “no” button when they decided whether they heard a sound or not. Each frequency was tested 3 times. If the results were not similar, then the block was repeated until satisfactory results were achieved. Longer duration tones should require lower sound intensity to be detectable than short duration tones. For a tenfold increase in duration (from 10 ms to 100 ms, for example) normal thresholds should have decrease by 10 dB.

It was expected that the results of this experiment would be similar to those of Hoglund and Feth (2009). The first listening condition was called the Temporal task: tones of one frequency but at different durations. The subjects listened to 4680 Hz tones at 10, 20, 40, 80, 160, and 240 ms respectively. For the second part, the Spectrotemporal tasks, the individuals listened to tones that change in frequency over time and at different durations. The tones were introduced at a high frequency and changed to low. There are two different spectrotemporal tasks: Linear and Step. The Linear task has a gradual change in frequency and looks like a descending line on a graph. The Step task has a much more rapid change in frequency so that the frequency jumped from one to another in steps (see Figure 4). There are a total of 8 steps in the Step task. Both spectrotemporal tasks begin at 7334 Hz and end at 1125 Hz and the durations used were 20, 40, 80, and 160 ms.

The reason for this setup is because, in the Hoglund and Feth experiment, the subjects with normal hearing and NIHL both improved greatly with short bursts, but it is hypothesized that those with NIHL hear each burst as a new sound which interprets in their brain as an increase in intensity. Each time a new burst starts, the NIHL subjects are able to hear it, but when a longer tone is presented that only has one beginning, they may not hear it as well. So to determine if there is NIHL, or the possibility of NIHL, longer tones must be used.

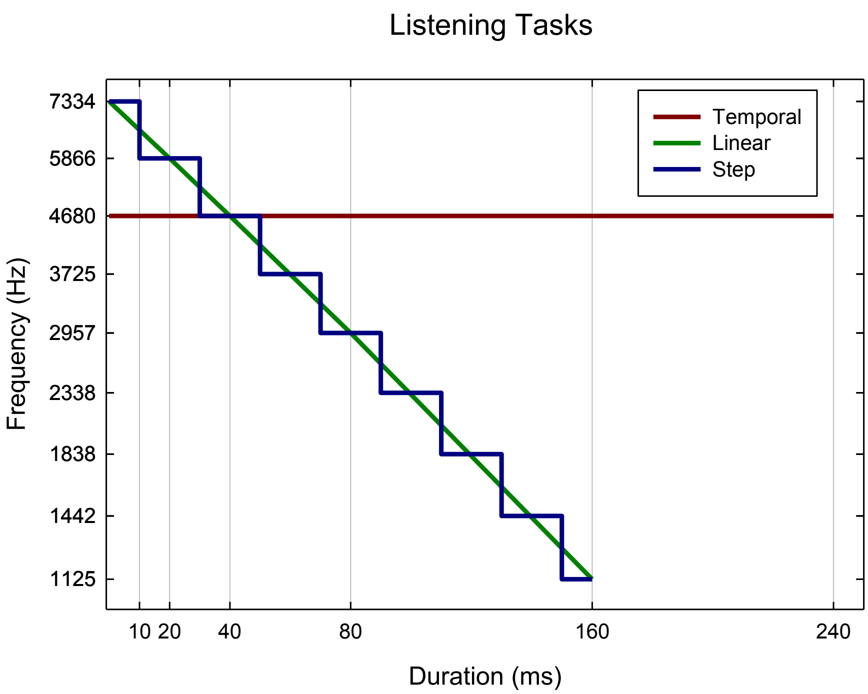

Figure 4: The structure of the listening tasks given to the subject

- *X axis = duration of tones*
- *Y axis = frequency of tones*
- *Red line = Temporal*
- *Green line = Linear (spectrotemporal)*
- *Blue line – Step (spectrotemporal)*

The right ear was tested and the tasks were given in a different order from subject to subject to make sure that the subjects did not experience practice effects to avoid getting better thresholds on the later tests just because they learned to listen and recognize those sounds better. Subjects were encouraged to take a break if they felt fatigued to reduce fatigue related errors. Every participant had previously filled out a consent form that described the lab tasks in detail. An oral explanation and directions were also given.

Materials

A custom made computer was used in this procedure to play the tones, as well as MATLAB computer software. The individuals used Senheiser HD250 headphones monaurally. Experiments used an adaptive testing procedure, Single Interval Adjustment Matrix, SIAM. The test started at a comfortable hearing level and gradually decreased in sound pressure level (SPL) until the sound was below the subject's hearing threshold. At this point the SIAM adjusted the level until the subject could hear the sounds again. The computer program found the level that the listener got 75% right. This process was repeated for every duration at a single frequency and for the tones with varied frequencies.

RESULTS

The questions that were asked in this study are: can this study replicate the original brief tone experiment? If it can, will there be a difference in the data of the original brief tone task and the two new spectrotemporal tasks? Questions pertaining to the hypothesis were also asked; is Step the best task in improving normal hearling thresholds? Will the subjects' thresholds increase with increasing duration?

Temporal vs Spectrotemporal and Linear vs Step

The subjects' thresholds improved significantly with all three conditions (see Figure 5). All tests had an approximate 10 dB threshold improvement between 20 and 160 ms. The Temporal condition closely matched the brief tone experiment done by Olsen (1974).

Long Tones vs Tone Pulses

Compared to the ongoing Hoglund and Feth research this longer tone experiment has a bigger threshold improvement. All three test results are mostly clustered within 5 dB or less of each other at any given frequency.

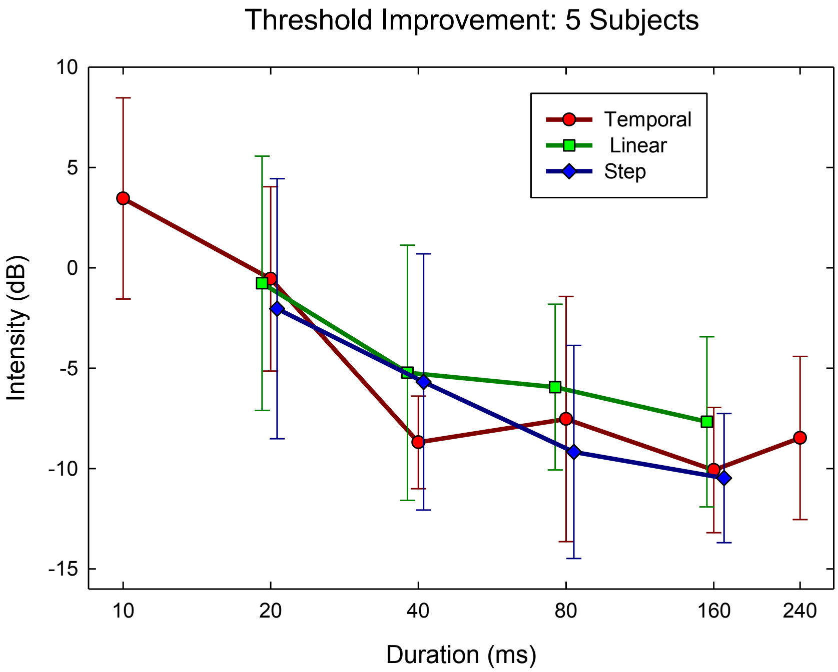

Figure 5: mean threshold from the three listening tasks average results

- *X axis = duration of the tone*
- *Y axis = dB improvement*
- *Red line = Temporal*
- *Green line = Linear (spectrotemporal)*
- *Blue line = Step (spectrotemporal)*
- *Error bars = span of subject results*

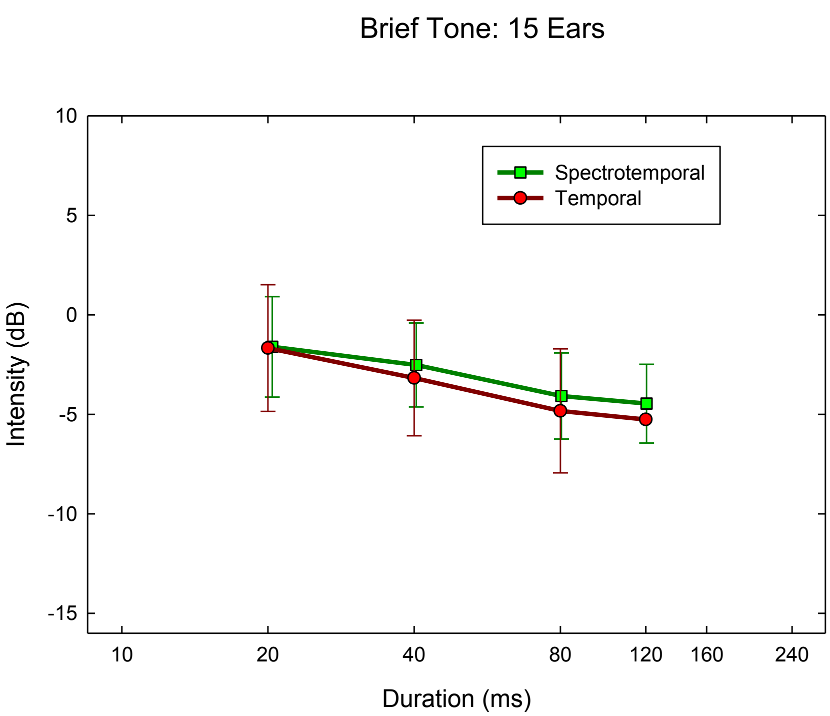

Figure 6: Hoglund & Feth tone burst experiment

- *Axes the same as Figure 5*
- *Green line = Spectrotemporal*
- *Red line = Temporal*
- *Error bars = span of subject results*

DISCUSSIONS

The purpose of this experiment was to find the best task to detect early onset of NIHL. Three tasks were developed for this purpose: two spectrotemporal, and one temporal. The three tasks are called Temporal, Linear, and Step. The Temporal task is tones of different duration, but always at 4680 Hz, which was the brief tone experiment performed in the past. The task was to match the previous results to make sure that it is possible and to have something for the new tasks to compare to. The Linear and Step both change with time and frequency starting at 7334 Hz and ending at 1125 Hz. The difference between Linear and Step is that Linear gradually changes in frequency, while the Step sharply changes in frequency in total of 8 steps.

Normal hearing subjects were used in this experiment that are going to be used as a baseline for further experiments with NIHL individuals. To figure out which task is the best, data from 5 normal hearing subjects were collected and the average plotted on a graph. The task with the biggest threshold improvement, the steepest slope, was to be the best task. The hypothesis was that as duration increased, the subject threshold increased, and that the spectrotemporal tasks would be better than temporal, and that Step would be the better spectrotemporal task of the two. Duration increase adds overall extra energy to a tone because of better temporal summation. The hypothesis of spectrotemporal being better than temporal, and Step being the best was based on the fact that an abrupt change in frequency spreads energy to frequencies that surround the frequency of the tone (Hoglund & Feth 2009). The listeners may hear a click when this splatter occurs in Step, but not in the Linear task. This click may cue the listener that the sound is happening.

Normal Hearing Subjects and Frequency Change

Figure 5 and 6 baseline experiment was done with individuals' thresholds at 10 ms. 0 dB on both Figure 5 and 6 equals to the 10 ms threshold results from the baseline experiment. The threshold showed improvement when the detection was bellow 0 dB, so negative numbers equal improvement, while positive numbers mean that these tones needed extra intensity to be heard. The reason that the spectrotemporal conditions started at 20 ms instead of 10 ms was because extra duration was needed for frequency change.

The temporal results were successfully replicated and matched the original Olsen brief tone results (1974). When these results were compared to the two new spectrotemporal tasks, it was evident that there was no major difference between the tasks. This may mean that frequency change does not make much difference in threshold detection for normal hearing subjects. However, there was a significant threshold improvement with the increase of time as was hypothesized in all 3 tasks and based on previous brief tone experiments such as Olsen's.

Energy In Long Tones vs Tone Bursts

These results were compared to the Hoglund & Feth ongoing experiment with tone pulses, and it appears that the threshold improvement seems to be better with long tones than tone pulses. It also appears that onset cues used in the multiple burst experiment did not help the listener detect longer duration sounds as was thought by Hoglund and Feth. This study more closely follows the energy detector model of 3 dB improvement for each doubling of duration that was created by Green (1958). The reason that the threshold improvement is great with long tones versus tone pulses may be because durations for long tones had more energy than tone pulses since 50% of the tone in the Hoglund and Feth experiment was silence. The actual sound duration was twice as long in this experiment than in the tone pulse experiment for every total duration, including tones and silent gaps.

Future Implications

NIHL subjects must be tested using the spectrotemporal tasks since it is not always clear which exact frequencies are affected by noise. A great starting subject pool would be the military and construction and factory workers. Individuals in these fields of employment are exposed to intense sounds sometimes on a daily basis.

It's also important to keep in mind that early onset of NIHL may only affect very small bands of frequencies (Henderson & Hamernick, 1995), so very large jumps in frequencies while testing may not be suitable in detecting the early onset subjects. A normal audiometric test generally checks the hearing level frequencies at 250, 500,1000, 2000, 4000, and 8000 Hz, and sometimes also at 125, 750, 1500, 3000, and 6000 Hz. Also the testing is done in 5 dB steps. What if the narrow band does not include any of those frequencies but is in between them and is also a smaller dBHL loss than 5 dB? The audiologist may not be able to detect this early onset. This is why the basic audiometry testing may not spot NIHL until it has already progressed to a significant hearing loss. So when testing for the early onset, it's important to use narrow frequency changes in the high range and small dB changes.

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